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MONOGRAPHIC SECTION

Climate change and occupational allergies: an overview on biological pollution, exposure and prevention

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Abstract

Introduction. Climate change, air pollution, temperature increase and other environmental variables are modifying air quality, contributing to the increase of prevalence of allergic respiratory diseases. Allergies are complex diseases characterized by multilevel interactions between individual susceptibility, response to immune modulation and environmental exposures to physical, chemical and biological agents. Occupational allergies introduce a further complexity to these relationships by adding occupational exposure to both the indoor and outdoor ones in the living environment.

Objective. The aim of this paper is to overview climate-related allergy affecting environmental and occupational health, as literature data are scanty in this regard, and to suggest a management model of this risk based on a multidisciplinary approach, taking the case of biological pollution, with details on exposure and prevention.

Conclusions. The management of climate-related occupational allergy should take into account preventive health strategies, environmental, public and occupational interventions, as well as to develop, implement, evaluate, and improve guidelines and standards protecting workers health under changing climatic conditions; new tools and strategies based on local conditions will have to be developed. Experimental studies and acquisition of environmental and personal data have to be matched to derive useful information for the scope of occupational health and safety.

Key words
- climate change
- allergy
- biological products
- worker
- air pollution

INTRODUCTION

Article 1 of the Framework Convention on Climate Change (UNFCCC) defines climate change as *a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods* [1].

Climate change in IPCC's (Intergovernmental Panel on Climate Change) position refers to a change in the state of the climate that can be identified (*e.g.* using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, due to natural variability or as a result of human activity; it is responsible for increased temperature, rise in the sea level, modified air quality [2].

"Air pollution is the contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere". Household combustion devices, motor vehicles, industrial facilities and forest fires are common sources of air pollution. Pollutants of major public health concern include particulate matter, carbon monoxide, ozone, nitrogen dioxide and sulfur dioxide. "Changes in temperature, modifications in pre-

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cipitation frequency, and air stagnation also affect air pollution levels with significant risks to health. Climate affects pollution levels through pollutant formation, transport, dispersion, and deposition. For instance, fine particulate air pollution is estimated to be responsible for 7 million additional deaths globally in 2012, mainly due to respiratory and cardiovascular disease. Its effect is amplified by changes in ambient temperature, precipitation frequency, and air stagnation – all crucial for air pollutants formation, transport, dispersion and deposition". Outdoor and indoor air pollution contributes to the increase of the prevalence of allergic respiratory diseases [3], exacerbating clinical features.

The 2015 Lancet Commission on Health and Climate Change "recommends that over the next 5 years, governments: Invest in climate change and public health research, monitoring, and surveillance to ensure a better understanding of the adaptation needs and the potential health co-benefits of climate mitigation at the local and national level" [4].

Occupational allergies are complex diseases because of the influence of environmental and climatic factors, the presence of allergens of different origin, the individual sensitization and immunological responses, the clinical manifestations: different and complementary medical skills are required for their management [5].

The topic *climate change* linked to the *occupational health* requires a particular attention by authorities in order to promote research, monitoring, surveillance, best practices, protective and preventive measures, starting with specific control program regarding occupational health and evaluation of environmental and climate factors. According to the scientific literature, thermal stress, injuries and fatalities are the main consequences of climate change in the workplaces [6, 7].

Allergic and respiratory diseases in relation to climate change have been extensively studied with regards to public health but little attention has been payed on climate-related allergic and respiratory diseases in the occupational sector, although some pertinent concerns are well known since several years [5, 8-14].

In Italy occupational health and safety are regulated by the Legislative Decree 81/08, implementing the EU directives on the improvement of health and safety at work. Article 28 (Title I - Common principles) of the Decree states that the employer has to assess all risks for health and safety of the workers. However, the allergic risk is explicitly mentioned in the Title X of the Decree (*Exposure to biological agents*) and particularly in the annex XLVI, where *possible allergic effects* are reported for 10 agents (2 parasites and 8 fungi) with respect to the 375 classified biological agents [15].

In this study we focused our attention on outdoor and indoor biological pollution, exposure and prevention related to climate change, with the aim to emphasize a topic – allergy – affecting environmental and occupational health and to remark the need to manage this risk in a multidisciplinary way. We also stress the importance of studying not only well known occupational allergens such as latex, house dust and flour, but also allergies caused by new indoor and outdoor sources of exposure.

PLANTS AND ANIMALS DERIVED AEROALLERGENS, CLIMATE CHANGE, ENVIRONMENTAL POLLUTION

Allergens and sensitizing agents are traditionally classified as high-molecular-weight (HMW) (glyco) proteins of animal and vegetable origin, mainly represented by grain dust (including mites), bakery dust, fish proteins, laboratory animals, bird proteins, natural rubber latex, enzymes (especially in detergents), mold proteins, vegetable gums, soy bean dust, cotton, coffee, and other seed dusts. Low-molecular weight (LMW) agents are metals, acid anhydrides, isocyanates, biocides, reactive dyes and others [16].

Although HMW proteins generally induce an IgE-response, involved in the pathogenesis of respiratory diseases (asthma, rhinitis, etc.), and LMW agents can causes T-cell dependent delayed-type reactions, the pathogenic mechanism of many of them is still unknown, for instance cases of occupational contact urticaria caused be parvalbumin, and respiratory diseases induced by some chemical agents, as reported in the literature [16-21].

The beginning and development of occupational allergic diseases are regulated by a complex interaction which includes endogenous and exogenous factors, individual susceptibility, exposure in living and working environments with different level, duration and frequency, etc. Moreover, the influence of climatic and environmental drivers on physical, chemical and biological pollutants also plays an important role in the onset of allergic diseases [8, 22-24].

A lot of allergens are affected by climatic and environmental variations, and many studies considered the effects of climate change and chemical pollution on the features and seasonality of pollen and plant flowering; influence on individual susceptibility, genetic variations, health consequences such as respiratory and allergic diseases have also been reported [9, 25, 26].

In this regard, a comprehensive and detailed biointeractive model to justify the increased prevalence of asthma and allergic diseases observed in recent decades [27-31] is still lacking.

Climate change and pollutants like greenhouse gases (GHGs), sulfur oxide (SO), particulate matter (PM), ozone (O_3), nitric oxide (NO) have pronounced negative effects on both environmental and human health. Fauna, plant species, pollen (including spatiotemporal dynamics of allergenic pollen) and other biological *components* are affected by climatic variation, atmospheric factors, meteorological conditions. All these factors determine an increased allergenic effects of both vegetable and animal components, inducing and/or exacerbating allergy and chronic respiratory diseases, as well as decreasing the lung function [31-42].

It is important to note that also indoor sources contribute to outdoor air pollution. Moreover, pollution arising from chemical, physical and biological agents affects climatic parameters (temperature, humidity, wind speed etc.), but the opposite is also true in both workplaces and living environments.

Institutional networks and associations ensure a continuous monitoring of pollen, fungal species distri-

Table 1
An overview of some institutional links regarding climate change, air pollution, public health and occupational health

Institution	Link
Agenzia Regionale per la Protezione Ambientale (ARPA)	web-sites
Associazione Italiana di Aerobiologia (AIA)	www.ilpolline.it
Centro Euro Mediterraneo sui Cambiamenti Climatici (CMCC)	www.cmcc.it
Centers for Disease Control and Prevention (CDC)	www.cdc.gov
Centro Interdipartimentale di Bioclimatologia (CIBIC)	www.cibic.unifi.it
Centro nazionale per la prevenzione e il Controllo delle Malattie (CCM)	www.ccm-network.it
Consiglio Nazionale delle Ricerche (CNR)	www.cnr.it
Ente Nazionale per l'Energia e l'Ambiente (ENEA)	www.enea.it
European Center for Disease Prevention and Control (ECDC)	http://ecdc.europa.eu
European Environment Agency (EEA)	www.eea.europa.eu
Global Framework for Climate Services (GFCS)	http://gfcs-climate.org
Intergovernmental Panel on Climate Change (IPCC)	www.ipcc.ch
International Labour Organization (ILO)	www.ilo.org
Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro (INAIL)	www.inail.it
Istituto Superiore di Sanità (ISS)	www.iss.it
Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA)	www.isprambiente.gov.it
Ministero dell'Ambiente e della Tutela del Territorio e del Mare	www.minambiente.it
Ministero della Salute	www.salute.gov.it
National Institute for Occupational Safety and Health (NIOSH)	www.osha.gov
Occupational Exposure to Hazaourds Agents (HazMap)	http://hazmap.nlm.nih.gov
Occupational Safety and Health Administration (OSHA)	www.osha.gov
United Nations Framework Convention Climate Change (UNFCCC)	www.unfccc.int
World Allergy Organization (WAO)	www.worldallergy.org
World Health Organization (WHO)	www.who.int
World Metereological Organization (WMO)	www.wmo.int

bution and other biological emissions, as well as of parameters regarding climate and the environment *(Table 1)*. In this perspective, the integration of environmental and climatic data as well as the synergy between different institutions in order to promote the protection of public and occupational health should be highly beneficial.

IMPACT OF CLIMATE CHANGE ON OCCUPATIONAL EXPOSURE

Outdoor workers are at high risk for exposure to allergens of biological (animal and vegetable) origin, because of the prolonged permanence in the workplace or the intense physical activity characterizing some working tasks resulting in an increased respiratory inhalation. Indoor environment can also be affected by climatic variations, as some environmental parameters and various types of pollutants increases the interchange, making recognition of a clear separation between indoor and outdoor difficult.

Several criticisms are inherent to occupational allergies of biological origin, such as the identification of all the biological agents with potential allergenic effects, since current regulation (in Italy the Legislative Decree 81/08 - annex XLVI: *Biological agents classified*) recognizes only ten biological agents with regard to allergic effects *(Table 2)*; moreover, evaluation of the role of several co-factors involved in both the individual susceptibility and allergic responses is still lacking. In addition several professional categories are potentially exposed to allergic risk. Construction, agriculture, animal husbandry, fishing, hunting, park maintenance, farming, forestry, urban rescue and safety are representative of outdoor workplaces; therefore subjects operating in the urban (ecological operators, safety and rescue operators, sport instructors, gardeners etc.) and suburban (farmers, ranchers, gardeners, beekeepers, foresters, safety's operators, surveillance activity etc.) environments can be defined outdoor workers. In this context risk assessment shall be performed, taking into account environmental data arising from physical, chemical and biological parameters as well as from results of health surveillance of exposed workers.

Occupational allergies have been traditionally studied in indoor environment (*i.e.* offices, schools, bakeries, hospitals) where main allergens are mites, dusts, latex, and other (micro)components [43-46]. In most cases, different methodologies have been applied to evaluate both the environmental exposure (air and sampling monitoring) and the immune response (skin tests,

Table 2
List of the classified biological agents with possible allergic effects

Classified biological agents = 375*		
Bacteria		N = 151
Viruses		N = 129
Parasites		N = 69
Fungi		N = 26
Biological agents with possible allergic effects		N = 10
Parasites		
Biological agents	**Classification**	**Notes****
Ascaris lumbricoides	2	A
Ascaris suum	2	A
Fungi		
Biological agents	**Classification**	**Notes****
Aspergillus fumigatus	2	A
Candida albicans	2	A
Coccodioides immitis	3	A
Cryptococcus neoformans var. neoformans (Filobasidiella neoformans var. neoformans)	2	A
Cryptococcus neoformans var. gattii (Filobasidiella bacillispora)	2	A
Epidermophyton floccosum	2	A
Microsporum spp.	2	A
Penicillium marneffei	2	A

*According to Annex XLVI – Legislative Decree 81/08
**A: Possible allergic effects

immunochemical methods, molecular assays) [47-49].

In order to contribute to a better understanding of occupational allergies, a bibliometric approach for the study of scientific literature was followed. The search criteria are shown in the Supplementary data 1-8 available online (*Supplementary Materials*); we used MeSH (*Medical Subject Headings*) Terms – *the NLM controlled vocabulary thesaurus used for indexing articles for PubMed* – regarding air pollutants or allergens or pollen or changes, climate, occupational health or occupational exposure, hypersensitivity or allergy and immunology or respiratory tract diseases. A limit of data searching was the lack of "outdoor" term. *Meva* (*MEDLINE Evaluator*) – *a free medico-scientific data mining web service to analyse bibliographic MEDLINE data* – was used as *post-processor condensing the endless list of a MEDLINE result by presenting counts, frequency distributions, contingency tables (relations) and detailed sorted lists of selected bibliographic fields*. We applied this bibliometric approach to the literature of the last 5 years. As we reported in a previous communication, the study of bibliometric sources showed that articles refer specifically to a particular allergic condition, a source of exposure to specific allergens (both vegetables and animals), preventive measures against specific occupational allergies. It's easy to extrapolate articles that deal with occupational allergies about *indoor* because this term is present in MeSH Terms, while terms *outdoor/external/outer* do not appear [50].

Workplaces may be an important source of exposure to air pollution, both outdoor and indoor, not only for dust and fumes, but also for vegetable and animal allergens; examples include arthropod allergens such as house dusts, mites and cockroaches, mammalian allergens derived from pets or pests, mouse, rats, horses, jellyfish, hymenoptera, wild and domestic species such as wasps, bees, hornets, etc. [43-46, 51-58].

Workers or working activities at risk of exposure to biological allergens are represented by flour millers, pastry makers, health-care workers, laboratory technicians, farmers, sea foods processing, baking products manufacturing detergent production, pharmaceutical industry, food industry, foresters, beekeepers, marine biologists, fishermen, scuba divers, gardeners, farmers, firefighters, foresters, municipal operators. Following exposure to allergen, clinical features may involve respiratory tract (occupational asthma is the most frequent work-related disease), eye and skin tissues, other systems following ingestion, contact and inoculation of the allergens. The management needs a multidisciplinary approach through innovative molecular methodologies applied to both environmental and biological matrices, medical history acquisition, health surveillance and control measures regarding outdoor and indoor environmental exposures [59-63].

The management of occupational allergy should take into account all factors regarding lifestyles, including hobbies and outdoor recreational activities, as well as indirect, no apparent exposure or passive carriage of

allergens [64-66]. It is also necessary to assess the co-exposure to other environmental factors such as solar radiation [67] that can modulate the immune response and the occurrence of symptoms at various grades of severity. Moreover it should be noted that *"one health frames the complex interactions between human, animal and environmental health, one health is a unique approach to cope with allergies, one health focuses on equity and is key for human sustainable development"* [68].

COLLABORATIVE, MULTIDISCIPLINARY AND INTEGRATED APPROACH

In public and occupational settings health prevention and promotion are intrinsically linked to education through information, training and communication. It is important to increase the awareness of workers regarding the risk derived from exposure to allergens and to define collective and individual control measures. Moreover, workers may be responsible for the spread of allergens to the community, carrying allergens through their clothes, hair and shoes. The innovative molecular methodologies on biological fluids that allow the determination of many allergens with a high degree of sensitivity are very useful if implemented during workers' health surveillance. It is likely that the development of molecular aerobiology will provide a more detailed approach in term of health impacts. A multidisciplinary approach is highly advisable to study the full spectrum of issues regarding climate change, aerobiology and clinical outcomes [69, 70].

Preventive health strategies should involve environmental, public and occupational interventions. Decision makers have the responsibility to develop, implement, evaluate, and improve guidelines and standards to protect workers' health under changing climatic conditions; new tools and strategies based on local conditions will have to be developed.

As shown in *Figure 1, Figure 2a and Figure 2b* (available online as *Supplementary Materials*) the study of biological occupational allergies should be performed by a multidisciplinary approach based on both traditional and innovative tools. Regarding exposure to vegetable allergens – pollens in particular – air monitoring is addressed to improve the new molecular approaches in addition to traditional methodology used by monitoring stations [69,70].

Starting from a list of allergens [20] it is necessary to know all information to manage the risk due to occupational allergy, such as sampling methodologies that should be standardized. In order to protect the health of both workers and the general public and to safeguard plants and animals, the development of new and innovative methods for sampling and measurement of (bio) pollutants should be a priority.

Our research is addressed to carry out strategies and programs for the management of outdoor occupational allergy, listed in following key points (*Figure 1, Figure 2a* and *Figure 2b*, available online as *Supplementary Materials*):

I. Climate change and occupational allergy diseases (CCOADs)
II. Allergy program control (APC)
III. Personal protective equipment (PPE)
IV. Communication, education and training (CET)
V. General and scientific information (GSI)
VI. Occupational and non occupational fields (ONOFs)
VII. Forecasting Models (FoMs)
VIII. Information and communication technology (ICT)

Consultation of the national and international literature supported by a bibliometric analysis confirmed the lack of research on the assessment of biological allergens in outdoor workplaces. This analysis provides information for research teams and audience to clearly identify or mark peculiar topics in investigated fields.

For the protection of public health, the presence of monitoring networks allows the sampling of pollen and fungal spores through techniques fundamentally based on the principles of gravitational deposition, inertial impact and sucking, using stationary samplers placed at certain heights above ground that allow sampling on an ongoing basis. The measurement of outdoor allergens is based on standardized methods (reading on a microscope slide) and new molecular technologies are currently being tested. The standardization of sampling aerobiological methodology should also be conducted at national and international level. As part of aerobiology some goals to be pursued include the harmonization of existing networks for monitoring biological particles, the development of strategies to combat pollution and the identification of the role of climate change in allergic diseases for public and occupational health purposes. It is necessary to define the role of the environment in the prevention of allergic diseases, the factors affecting levels of indoor and outdoor allergens and the methods to reduce exposure in the living and working environments, taking into account both the individual and environment exposure [5, 22, 23, 69-76].

Research topics should include action mechanisms, classification, prevention, epidemiological surveillance/registries, predictive biomarkers, molecular diagnosis, treatment response, phenotypes, serious illness/exacerbations, new treatments (biological vaccine and drugs). Data collected through the environmental networks should be matched with those concerning workers health. *Ad hoc* questionnaires, immunochemical and molecular tests to assess immunological and other physiological parameters are of paramount importance to plan appropriate technical, organizational and procedural interventions addressed at specific workplaces. Information, education and communication are unreplaceable tools.

Our research aim is to perform strategies and programs for the management of outdoor and indoor occupational allergy through an experimental, integrated and multidisciplinary approach, also considering mathematical models as valid tools to analyze emission and dispersion phenomena, contributing to design risk scenarios.

CONCLUDING REMARKS

Allergy is a complex disease characterized by multiple interactions between individual susceptibility, genetic background, response to immune modulation and environmental exposures to physical, chemical and biological agents. Occupational allergies amplify these

relationships by adding other factors, depending on the workplace exposures. Traditionally, the study of occupational allergies was focused on indoor pollutants, but the growing body of data about allergies in the general population and recent new evidences are a stimulus to extend research to outdoor environment, trying to understand the potential connection between indoor and outdoor allergens. Air pollution and climate change have a central role in the etiology and pathology of occupational allergies.

A great body of literature suggests that bibliometric indicators are one of the most common tools to measure research performance. Moreover, these indicators have a wide range of applications, such as *descriptive linguistics*, development of *thesauri*, evaluation of reader usage and measuring term frequencies.

It is necessary to promote a multidisciplinary approach starting from an exhaustive and detailed knowledge of the literature regarding allergies, together with the monitoring of physical, chemical and biological parameters, data on the immune-susceptibility of the workers and the influence of other co-factors. In addition, forecasting and mathematical models can be helpful to increase the knowledge and to suggest the preventive measures to adopt in this area.

In conclusion, climate change represents an issue that need to be explored and studied in its different and complex aspects. The impact resulting from temperature increase and air pollution, health consequences such as cardiovascular and respiratory diseases and accidents and other events is certainly recognized.

These features are the apical part of a phenomenon which – if not counteracted – can keep on and greatly damage the environment and human health. Local actions as well as national and international agreements are aimed at safeguarding the "universal health", since environmental and human health are interconnected. The questions regarding occupational health should be considered in an integrated life course approach [76-78].

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Conflict of interest statement

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